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Toxicity evaluation and management of co-composting pistachio wastes combined with cattle manure and municipal sewage sludge

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ABSTRACT

To manage the pistachio de-hulling waste (PW), investigated the co-composting process using a mixture of PW and cattle manure (CM) (5.5:10 dry weight) as well as PW and municipal dewatering sewage sludge (DSS) (1:10 dry weight) at the laboratory scale for 60 days. Compost toxicity was evaluated using the seed germination index (GI). The maximum temperatures in co-composting processes of PW + CM (51.9 °C) and PW + DSS (49.9 °C) were reported on the seventh day. The increase of temperature was higher in PW + CM and remained in the thermophilic phase for five days. In both reactors, the pH rates decreased, increased, and finally remained neutral. The C/N ratio decreased in both reactors, but the reduction rate was faster in the PW + DSS reactor. Sodium (Na %) and potassium (K%) contents were increased, while the concentrations of Cu, Zn, Fe, and Mn were decreased during the processes. The numbers of parasite eggs in the final composts of the reactors containing PW + CM and PW + DSS were zero and 8 Number/4gDW, respectively. The amounts of *Salmonella* were zero in the final products of reactors containing PW + CM and PW + DSS. The results of GI showed that the final compost of PW + CM process was not toxic for the plants, whereas the PW + DDS final compost was toxic. In conclusion, the co-compost product of the PW + CM reactor had higher quality than the PW + DSS reactor. So, it is suitable for PW management.

1. Introduction

Urbanization has led to an increase in the production of wastes and municipal waste management is considered as a big challenge worldwide (Ebrahimi et al., 2018; Salehi et al., 2011). Appropriate management of wastes, especially agricultural wastes is important for human and environmental health (Giusti, 2009; Song et al., 2015). Several researchers provided organic fertilizers from such organic wastes and used them for agriculture and horticulture purposes. They proved the advantages of organic fertilizers in terms of health and economics in comparison with other methods (Eslami et al., 2018; Lim et al., 2016; Shak et al., 2014). Pistachio de-hulling wastes are classified as the agriculture wastes and need appropriate management. The lack of proper management leads to pistachio contamination with *Aspergillus*, contaminations can discharge into the environment, cause annoying odors, and lead to the growth and proliferation of flies. Furthermore, burial of PW in pistachio gardens damages the roots because the PW materials are unstable and can interrupt the plant growth (Malakootian et al., 2014). High concentrations of organic and phenolic compounds as well as solids in PW have caused major problems in waste management (Demirer, 2016).

Co-compost process was considered as an appropriate strategy for agricultural waste recycling, including the pistachio wastes (Külcü and Yaldiz, 2014). Compost is a biological and environment-friendly process, through which the mesophilic and thermophilic aerobic microorganisms consume the organic matter as food and convert it into mineral products, such as CO_2, H_2O, and NH_4, or stabilized organic compounds, such as humic compounds (Bernal et al., 2009; Danon et al., 2008; Miaomiao et al., 2009). The final product of the composting process can be used on agricultural lands as fertilizers and on unsustainable lands as reformers (Hargreaves et al., 2008; Huang et al., 2006). However, application of large amounts of compost can cause

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negative effects on plants and humans (Hargreaves et al., 2008). Therefore, potentially dangerous factors should be determined and controlled regarding the safe use of compost for animals, plants, and humans (Smith, 2009). Pathogens and indicator bacteria are among the most important parameters to consider in evaluating the compost production technologies (Raj and Antil, 2011). Furthermore, compost products that contain high concentrations of metals can be toxic for animals, humans, and plants. As a consequence, metal poisoning causes serious injuries to kidneys, bones, and the nervous system in humans (Castaldi et al., 2006; Cesaro et al., 2015). On the one hand, the frequent use of compost may lead to accumulation of metals in the soil, which can be transmitted to humans through the food chain, groundwater, and plants (Hseu, 2004). On the other hand, lack of metals can lead to problems; for example, iron deficiency causes special discoloration called yellowing, which was observed in most soils as well as plants in Iran (Prashanth et al., 2015). Zinc deficiency and its dangerous complications were also observed in most calcareous, alkaline, and dry regions, as well as in the slightly acidic and neutral soils of Iran. Moreover, severe damage from zinc deficiency was reported in many fruit tree species (Kumssa et al., 2015; Saboor et al., 2012). The composting process can remove pathogenic agents and hazardous materials, such as heavy metals. It also has positive effects on the physical, chemical, and biological parameters of the soil (Tejada et al., 2006). A composition of raw material and the generated heat by thermophilic microorganisms can affect deactivation of pathogens directly and indirectly (Erickson et al., 2014). Therefore, in order to produce agricultural products with high quality, we need to improve the composting process. In this regard, the quality requirements include different physicochemical parameters such as temperature, humidity, C/N ratio, pH, electrical conductivity (EC), pathogens and indicator bacteria, as well as appropriate concentrations of metals and nutrients (Lasaridi et al., 2006; Tognetti et al., 2007). In order to have a successful composting process, all the above-mentioned parameters should be examined to be at the optimal levels (Kopčić et al., 2014). The best strategy for optimizing the physicochemical parameters is to combine two or more biodegradable wastes together (Iqbal et al., 2010; Rashad et al., 2010; Sundberg et al., 2011).

Considering the adverse effects of unstable and immature composts on germination, plant growth, and soil environments, the quality criteria of the compost such as stability and maturity should be evaluated before use (Bernal et al., 2009). High concentrations of compounds with low molecular weight such as organic acids and phenolic compounds, compounds such as ammonia nitrogen, salinity, heavy metals, and other xenobiotic compounds can be harmful to plants (Hase and Kawamura, 2012; Liu et al., 2009). In bioassay, seed germination index (GI) is used to determine the toxicity of compost and this method has attracted many researchers in recent years (Luo et al., 2017; Mamindy-Pajany et al., 2011; Selim et al., 2012). The GI calculates and evaluates the root length and seed germination percentages in compost samples as compared to the control samples. In fact, GI is associated with some biological and chemical indicators for assessing the quality of the compost (El Fels et al., 2016; Luo et al., 2017).

The objective of the study was to evaluate the performance of a new modified co-composting process in which a combination of pistachio de-hulling wastes (PW), cattle manure (CM), and municipal dewatering sewage sludge (DSS) was investigated for management of PW. Physicochemical, microbial, and metals' changes were also studied throughout the co-composting process. Then, the results were compared in mixtures of PW + CM and PW + DSS. Furthermore, to evaluate toxicity of the final compost, the GI and relative radicle growth (RRG) were calculated.

2. Materials and methods

2.1. Co-composting experimental setup

The present study was carried out at the laboratory-scale over a 60-day period. According to the initial evaluations, the waste products were mixed together in the ratios of 5.5:10 for PW + CM and 1:10 for PW + DSS in dry weight until the optimal ratio of C/N was reached. In PW + DSS process, sawdust (15% of the total mass weight) was added to the mass as a bulking agent. To increase dehydration, both treatments were placed in separate reactors. In this study, a 60-L cube-shaped plexiglass reactor with dimensions of 50 (L) x 40 (W) x 30 (H) cm was placed on a metal base. To collect the leachate, a grid with 5 mm holes was installed at the height of 10 cm from the reactor bottom. Furthermore, a faucet was embedded in the reactor bottom in order to extract the leachate produced in the composting process. In order to oxygenate the aerobic microorganisms, aeration was conducted by an air compressor with a 15 min-on /15 min-off cycle duration. The required input air flow was determined by a manometer based on the organic material weight in the reactor set at 0.41 L/min.kg.

2.2. Physicochemical, microbial, and metals' analysis

In order to measure the physicochemical parameters, sampling was conducted after each mix. In order to measure the temperature, C/N ratio, heavy metals, nutrients, fecal coliform (FC), parasites eggs, and *salmonella*, sampling was performed twice. To determine the percentage of nitrogen using the Kjeldahl method, the sample was first digested in a digester and read by a DR spectrophotometer, model 6000 (WEF et al., 1995). To measure the concentration of metals (Na, K, Fe, Mn, Zn, and Cu), the samples were first held at a temperature of 103–105 °C for 2 h. Then, they were digested with nitric acid, phosphoric acid, and sulfuric acid. Finally, the concentrations were measured by an atomic absorption spectrometry. After preparing the diluted solution, the percentage of Na and K were determined using a flame photometer. To determine the possible numbers of FC bacteria and parasite eggs, a specific culture medium A_1 and zinc sulfate were used, respectively (Forbes et al., 2005; WEF et al., 1995). After preparing the desired cultures, a 5-g sample was incubated in peptone water containing non-selective liquid enrichment culture medium. After 5 min, the medium was placed in an incubator shaker device at 37 °C for 16–20 h. Coliform colonies were identified using the nine-tube fermentation method and the A_1 medium. In the coliform test, three dilutions of 1, 0.1, and 0.01 were used under conditions of serological bain-marie at 41.5 °C for 20–24 h. To calculate the number of parasite eggs, a zinc sulfate solution was poured into a tube up to the half. Then, 1 g of the sample was transmitted into the tube and the suspension was prepared. Later, passed the suspension through a two-layer gauze and returned the filtered solution into the tube. Used the zinc sulfate solution and the solution surface reached 2–3 mm from the tuyere surface. In the next step, centrifuged it at 3000 rpm for 1 min. In order to perform the identification under the microscope, a loop was taken from the supernatant of the tube and added to a slide containing Lugol. To determine the amount of *salmonella*, the selenite F culture, XLD agar, TSI (Slants Triple Sugar Iron agar), and urea agar were applied. The incubation temperature was 37 °C for 24 h in all stages of measuring *salmonella*. The results of the bacterial tests were recorded in most probable number per gram of dry weight (MPN/gDW) (Goyal et al., 2005). In addition, compared the findings with New York State Association of Recyclers standard (Brinton, 2000).

2.3. Seed germination test

The seed germination method consists of three main stages: 1) Preparation of the extracted liquid compost, 2) incubation of the seeds with the extracted liquid compost, and 3) measurement and calculation of the indices related to the test results using the following Eqs. (Eqs. (1)–(4)).

$$SG = \frac{\text{Number of germinated seeds}}{\text{Number of total seeds}} \times 100 \quad (1)$$

$$RSG = \frac{\text{Number of germinated seeds(sample)}}{\text{Number of germinated seeds(control)}} \times 100 \quad (2)$$

$$RRG = \frac{\text{Total radicle length of germinated seeds(sample)}}{\text{Total radicle length of germinated seeds(control)}} \times 100 \quad (3)$$

$$GI = RSG \times RRG \times 100 \quad (4)$$

Where: the seed germination (SG), the relative seed germination (RSG), the relative radicle growth (RRG) and the seed germination index (GI) (Luo et al., 2017).

To calculate the germination index, the compost was mixed with deionized water with a ratio of 1:5; later, the liquid compost was shacked for 24 h at 25 °C with 200 rpm and passed through a filter paper. Then, the liquid compost was extracted with 0% or the control sample (0 ml liquid compost, 100 ml distilled water), 0.5% (0.5 ml liquid compost, 99.5 ml distilled water), 1% (liquid compost 1 ml, deionized water 99 ml), 5% (5 ml liquid compost, deionized water 95 ml), 10% (10 ml liquid compost, 90 ml distilled water), 20% (20 ml liquid compost, 80 ml distilled water), 40% (60 ml of liquid compost, 60 ml of distilled water), 60% (60 ml of liquid compost, 40 ml of distilled water), 80% (80 ml of liquid compost, 20 ml of distilled water), and 100% (liquid compost 100 ml, deionized water 10 ml). In the next step, 1 ml of the extracted compost was poured into 10-petry dishes for the germination assay. Then, 20 seeds of Chinese cabbage (*Brassica pekinensis* Rupr), which are highly sensitivity to the compost toxicity were added into all Petri dishes. Later, the petri dishes were incubated in a dark environment for 2 days at 25 °C and the number of germinated germs and the length of the radicle growth were measured (Mitelut and Popa, 2011).

2.4. Statistical analysis

The results were compared with the standard rates using a T-test analysis and the removal efficiencies were compared with various operating times using the two-way analysis of variance (ANOVA) at a significance level of 0.05. The mean and standard deviation (SD) were obtained from three replicate experiments.

3. Results and discussion

The physicochemical characteristics of the raw mixture and the final compost from PW + CM and PW + DSS are presented in Table 1.

3.1. Temperature changes

In Fig. 1a, the changes of temperatures during the 60-day composting process are shown for the reactors containing PW + CM and PW + DSS. On the second day, a significant temperature increase was observed in both reactors. On the seventh day, both co-composting processes reached the maximum temperature (51.9 °C for PW + CM and 49.9 °C for PW + CM). Regarding the PW + CM process, a greater temperature increase was reported, which remained in the thermophilic phase for five days and resulted in the decomposition and stabilization of organic matter in the PW + CM and the destruction of pathogenic microorganisms in the final product (Bernal et al., 2009). Considering the PW + DSS process, the maximum temperature was maintained for three days, which was insufficient to destroy the pathogenic microorganisms as well as the organic matter decomposition and stabilization. Finally, the temperature began to decrease in both co-compost masses and reached the ambient level on the 60th day.

3.2. C/N ratio changes

The C/N ratio showed a significant ($p = 0.005$) decreasing trend during the co-composting process in both reactors (Fig. 1b). In PW + CM co-composting, the ratio changed from 25:1–13:1 and in PW + DSS co-composting, it decreased from 25:1–14:1; the decrease rate of the C/N ratio was higher in PW + CM. The C/N ratio is used as an indicator of compost stabilization and shows the level of decomposition in the organic compound during the composting process (Huang et al., 2006; Meunchang et al., 2005). The decrease in the C/N ratio was due to faster C consumption and slower N consumption (N was almost constant) by microorganisms throughout the composting process. Therefore, it can conclude that the process of organic compound decomposition is faster in PW + CM process. The C/N ratio was in the standard range (less than 15:1) in the final compost of both reactors (Brinton, 2000).

3.3. Changes in pH and EC

Electrical conductivity (EC) and pH are among the most important parameters in monitoring the composting process and in determining the quality of its final product (Hosseini and Aziz, 2013). The pH rates changed during the co-compositing process in both reactors (Fig. 2a). With the onset of the process, observed an increase in bacterial activity, the biodegradation of organic materials, and the formation of organic acids. As a result, pH decreased from 6 in the PW + CM process to 5.8 in the PW + DSS process. The second *meso*philic phase was characterized by an increase of pH in both reactors. The results of ANOVA test showed that these changes were statistically significant ($P \leq 0.001$). The decline in pH was due to the formation of organic acids, incomplete oxidation of organic matters, nitrification, formation of ammonium gas and its emission into the atmosphere, and eventually the emission of hydrogen gas (Wong et al., 2001). The optimal pH for bacterial activity in the composting process is in range 6.7–9 (Brito et al., 2012). The final pH rates were 7.9 and 7.7 in the PW + CM and PW + DSS processes, respectively; both were in the standard range (Brinton, 2000).

Fig. 2b represents the EC changes in the co-composting process. A significant increase was observed in EC of both reactors ($P = 0.009$); EC increased from 1.4 to 3.1 mmhos/cm in PW + CM and from 1.2 to 2.9 mmhos/cm in PW + DSS. The increase of EC during the composting process was attributed to the mineralization of materials and the accumulation of minerals (Sánchez-García et al., 2015).

3.4. Metals change

The changes of sodium (Na%) and potassium (K%) micronutrients during the co-composting processes are shown in Fig. 3a and b. Sodium and potassium increased throughout the co-composting process in both reactors, sodium was higher in PW + CM than PW + DSS, and potassium was significantly higher in PW + DSS than PW + CM ($p = 0.002$). Furthermore, the co-compost sodium produced in PW + CM process was significantly higher than PW + DSS. In order to produce the compost, added sawdust to the urban waste mass and found that the Na content increased. The increasing rate of sodium and potassium contents during the process can be due to the reduction of organic material contents. Since consumption of Na and K was less than other minerals during the process, their remaining concentrations were higher in the the produced compost (Sailila et al., 2011). Copper (Cu) and Zinc (Zn) concentrations decreased significantly ($p \leq 0.001$) in both reactors during the co-composting process (Fig. 3c and d). The final co-composting products showed that the concentration of Cu decreased from 69 ppm to 21.5 ppm in PW + CM process and from 41.1 ppm to 26.6 ppm in PW + DSS process. Moreover, the Zn concentration decreased from 193 ppm to 93.5 ppm in PW + CM process and from 64.3 ppm to 33.8 ppm in PW + DSS process. However, the reduction rates of Cu and Zn concentrations were higher in PW + CM process in comparison with

Table 1
Physical and chemical parameters from the co-composting process of PW + CM and PW + DSS.

parameter	Co-composting of PW + CM		Co-composting of PW + DSS	
	Initial mixture (mean ± SD)	Final compost (mean ± SD)	Initial mixture (mean ± SD)	Final compost (mean ± SD)
C/N	25.34 ± 5.1	13.21 ± 2.1	25.86 ± 4.61	14.65 ± 1.7
pH	7.1 ± 0.7	7.9 ± 0.5	7.06 + 1.1	7.7 ± 0.9
EC (mmhos/cm)	1.9 ± 0.1	3.1 ± 0.8	2.17 ± 0.6	2.9 ± 0.54
Moisture content (%)	35.75 ± 4.3	20.32 ± 3.3	17.25 ± 2.2	18.65 ± 2.4
Organic carbon (%)	64.45 ± 11.4	43.03 ± 5.1	70.26 ± 8.1	36.68 ± 4.1
TN (%)	2.54 ± 0.8	3.25 ± 0.4	2.71 ± 0.6	2.51 ± 0.1
Ash (%)	15.63 ± 4.9	22.5 ± 5.9	23.21 ± 8.7	33.98 ± 7.5
Volatile Solids (%)	84.36 ± 6.2	77.5 ± 5.1	80.82 ± 10.8	66.2 ± 8.2
K (%)	3.6 ± 1.3	4.1 ± 1.4	1.4 ± 0.1	6.01 ± 1.2
Na (%)	0.25 ± 0.1	0.69 ± 0.3	0.15 ± 0.1	0.47 ± 0.2
Cu (ppm)	69.1 ± 9.2	21.5 ± 4.8	48.1 ± 7.7	26.6 ± 6.7
Zn (ppm)	193 ± 10.1	93.5 ± 9.8	64.3 ± 7.6	33.8 ± 5.9
Fe ((ppm)	0.21 ± 0.1	0.12 ± 0.1	0.21 ± 0.2	0.14 ± 0.1
Mn (ppm)	150 ± 11.4	119 ± 9.5	125 ± 10.7	63.5 ± 8.4
Fecal coliform (MPN/gDW)	11,000	540	15×10^6	3650
Salmonella (MPN/4gDW)	10	0	20	0
Parasite eggs (Number/4gDW)	4	0	25	8

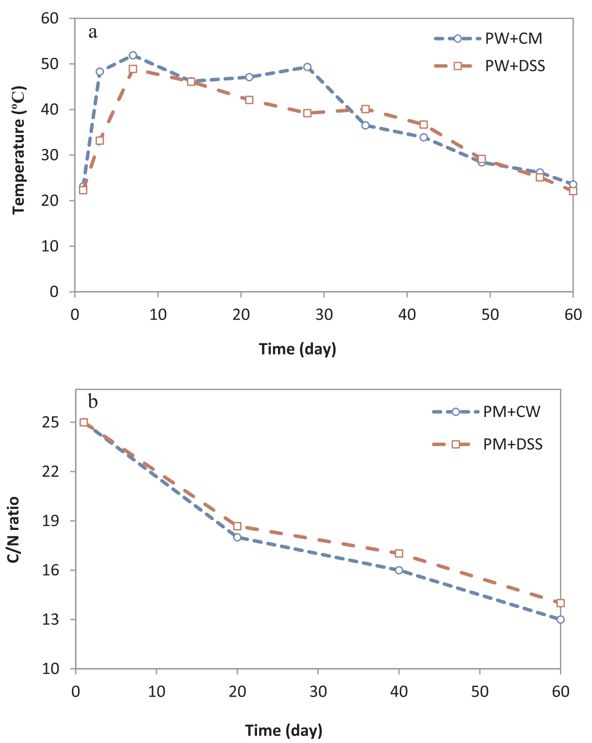

Fig. 1. Temperature (a) and C/N ratio (b) changes during the co-composting process.

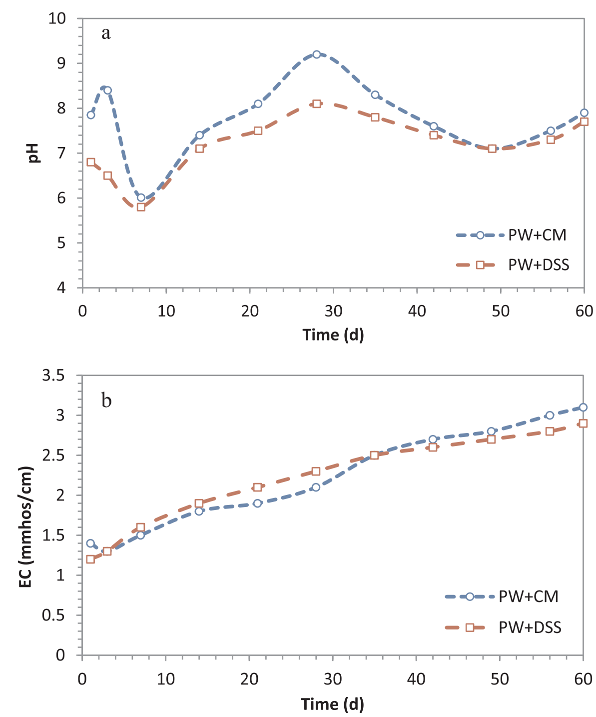

Fig. 2. pH (a) and EC (b) changes during the co-composting process.

those of PW + DSS process. Regarding the final compost product, Cu and Zn concentrations were lower than the standard for final compost product (Brinton, 2000). Decrease of the metal concentrations in the composting process can be related to the decomposition of organic materials and mineralization process (Liu et al., 2007). This finding was consistent with the results of a study conducted by Xuejiang et al., in which Cu and Zn changes were assessed during the composting process of wastewater sludge with sodium sulfite and lime. Their findings indicated a decrease in the concentration of Cu and Zn (Xuejiang et al., 2008). Total iron (Fe) concentration decreased significantly ($p = 0.004$) during the co-composting processes in both reactors; the final Fe concentration reached 0.14 ppm in PW + CM and reached 0.12 ppm in PW + DSS process (Fig. 3e). Total manganese (Mn) concentrations were greater in PW + CM than the PW + DSS process ($p = 0.006$). The final amount of Mn was 119 ppm in PW + CM, while it was 63.5 ppm in PW + DSS process (Fig. 3f). In the final co-composting products, concentrations of Fe and Mn were lower than the compost standard in both reactors (Brinton, 2000).

3.5. *Microbial parameters Changes*

The primary FC level was 15 × 106 MPN/gDW in PW + DSS. The highest removal efficiency occurred in the thermophilic phase at the end of the process (i.e., on the 60th day) and FC reached 3650 MPN/gDW. The initial amount of FC was 11,000 MPN/gDW in PW + CM, 2100MPN/gDW in the thermophilic phase, and reached 540MPN/gDW at the end of the co-composting process (Fig. 4a). Fecal coliforms, as one of the most important parameters in evaluating the microbial quality of organic compost (Qian et al., 2014) are destroyed at the temperature of 55 °C and remain for 1–5 days. Therefore, in order to

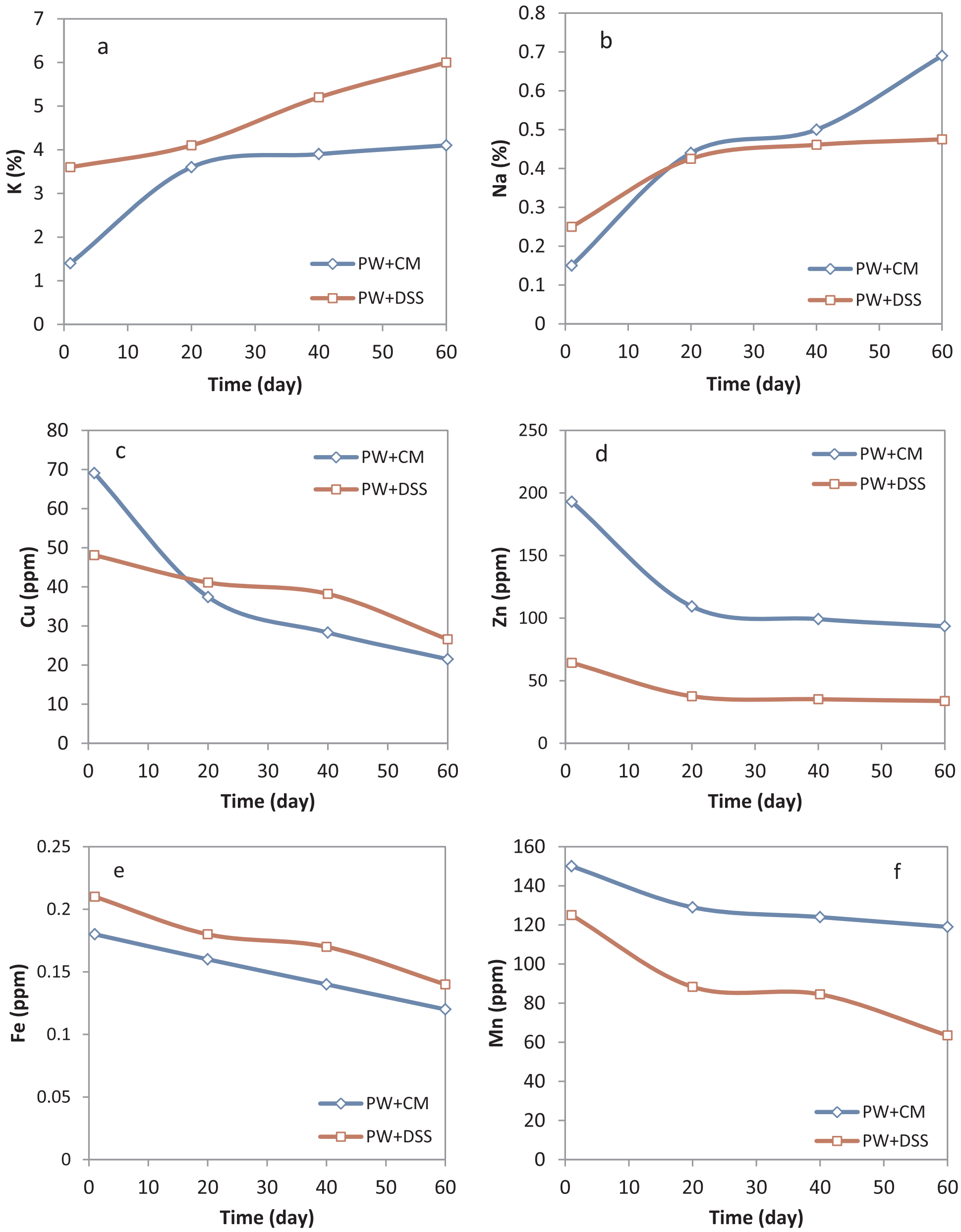

Fig. 3. Metal changes during the co-composting processes, Na (a), K (b), Cu (C), Zn (d), Fe (e), and Mn (f).

meet the microbial standards in the final product, reaching this high temperature in the thermophilic phase is very important (Khan et al., 2009). According to the standard of FC in compost (≤1000 MPN/gDW), the compost produced in PW + CM process is in the standard range, but the compost produced throughout the PW + DSS process is not in the standard range (Brinton, 2000). The initial amounts of Salmonella were 20 and 10 MPN/4gDW in PW + DSS and PW + CM, respectively. This rate reached zero at the end of the process (Fig. 4b). Salmonella, as one of the microbiological indicator parameters was also evaluated in the final product. According to the microbial standards of Salmonella in the final product of compost (≤ 3 MPN/4gDW), the compost produced through PW + DSS and PW + CM were in the standard range (Brinton, 2000). The initial numbers of parasite eggs were 25 and 4 per 4gDW in PW + DSS and PW + CM, respectively. These numbers reached 0 per 4gDW and 8 per 4gDW in the final products of PW + CM and PW + CM, respectively (Fig. 4c). According to the standard for the number of parasite eggs (< 1 per 4 gDW), the compost produced by PW + CM was in the standard range, but the compost produced during PW + DSS was not in the standard range (Brinton, 2000). The results of this study were consistent with those of Kato (Kato and Miura, 2008) and Moreira (Moreira et al., 2008).

3.6. Toxicity evaluation

The GI and RRG indices calculated in different concentrations of compost extraction for PW + CM and PW + DDS are presented in Tables 2 and 3, respectively. The GI index of PW + CM process was higher than 80% in all extracted composts (except the 80% extraction ratio), but the GI index of PW + CM process was higher than 100% for the extraction ratios of 5–60% and was lower than 80% for the extraction ratios of 80–100%. The GI and RRG values, which were higher than 80% indicated that the compost did not have phytotoxicity (Luo et al., 2017). As a result, the compost achieved from PW + CM process was not toxic to the plant even at the liquid compost extraction ratios of 100%. However, the compost derived from the PW + DDS process was toxic to the plant at the extraction ratios of higher than 60%. In fact, the

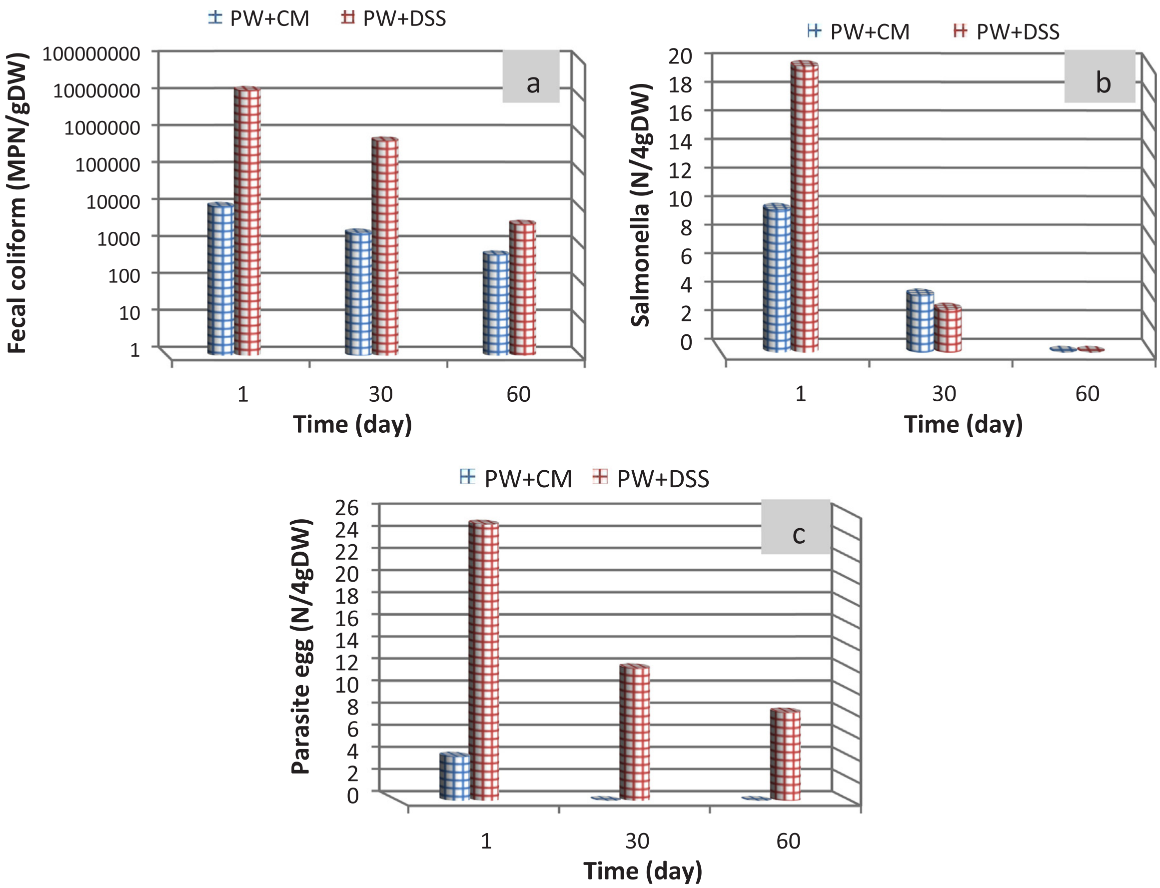

Fig. 4. Changes in microbial parameters during the reactor co-composting processes: (a) fecal coliform, (b) Salmonella, and (C) parasite eggs.

Table 2
Seed germination index parameters for PW + CM.

Compost extraction (v/v)	SG (%)	RSG (%)	Radicle length (mm)	RRG (%)	GI (%)
Control	93	94	2.5	150	141
0.5	85	100	5.5	120	120
1	83	94	5	100	94
5	82	106	7.5	114	120
10	80	100	10	100	100
20	85	100	12	118	118
40	75	100	14	115	115
60	67	107	12.5	108	192
80	53	90	7.5	87.5	78
100	40	100	8.5	88	88

Table 3
Seed germination index parameters for PW + DDS.

Compost extraction (v/v)	SG (%)	RSG (%)	Radicle length (mm)	RRG (%)	GI (%)
Control	83	94	2.5	66	62
0.5	85	100	3	42	42
1	85	94	3	100	94
5	83	106	4.5	125	132
10	75	106	6	140	100
20	65	107	6.5	160	148
40	50	100	9.5	137	137
60	50	91	7.5	150	136
80	45	90	3	42	37
100	40	87	1.5	50	20

composting toxicity depends on the percentage of compost extraction. An increase in the amount of moisture of the compost promotes the amount of GI. Furthermore, the amount of EC compost affects the amount of germination. Therefore, the increase in EC and salts can prevent from the germination of seeds (Luo et al., 2017; Mattei et al., 2017).

4. Conclusion

An efficient co-composting process was achieved using the combinations of PW + CM and PW + DSS processes over a 60-day period. The increase of temperature was greater in the PW + CM process, which led to more effective pathogen destruction. The pH of the final product was within the standard range for both reactors and EC increased in both co-compositing reactors. However, C/N ratios decreased in both reactors and decomposition of organic compounds was faster in the PW + CM process. The content of Na and K increased, whereas, all metals contents, including Mn, Fe, Zn, and Cu decreased. The levels of metal content in the final products were within the WHO standard range. The levels of pathogen and indicator bacteria decreased in both co-composting processes and were at the standard levels in PW + CM process, but FC and the number of parasite eggs were higher than the standard levels in PW + DSS process. The final product of compost derived from the PW + CM process was not toxic to the plant, but the compost achieved from the PW + DDS process could be toxic to the plant at the extraction ratios of higher than 60%. Finally, the compost produced throughout the PW + CM process, as compared to PW + DSS process was closer to the existing microbiological standards regarding the final products of compost.

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